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PUMPING CROTON WATER BY HYDRAULIC POWER: WATER SUPPLY OF NEW YORK[1]

By Winfred D. Hubbard[2]

The present water supply for that portion of Greater New York comprised in the Boroughs of Manhattan and the Bronx is obtained from the Catskill and Croton sources. Water from the Catskills is delivered by gravity to Hill View reservoir, an equalizing reservoir located on high ground north of the City at elevation 295, and is conveyed from this point to and through the city in a deep pressure tunnel. At various locations on the line of this tunnel, riser shafts are constructed, provided with chambers just below the street level in which are installed the valves and controlling devices which afford connections with the distribution system. The Croton gravity supply is delivered to Jerome Park reservoir in the Bronx at elevation 134, to the 135th street gate house (the terminus of the New Croton aqueduct) at elevation 124, and to the Central Park reservoir at elevation 119. A steam pumping station of about 30,000,000 gallons daily capacity is located at Jerome Park and two steam stations at 179th Street and 98th Street, with a combined capacity of about 60,000,000 gallons daily, receive water from the Croton supply.

The pressures under which water is delivered to consumers vary with the topography of the districts, the height of buildings and the friction losses in the distribution mains. These may be grouped into three classes; the High service which is chiefly supplied from the Catskill system, the Low service which is a Croton gravity supply, and the Intermediate service which is supplied by pumped Croton water or Catskill water at reduced pressure. In the latter cases, the reduction in pressure is accomplished by throttling the discharge of the valves controlling the outflow at the city tunnel riser chambers The areas comprising one class of service are not contiguous but are distributed throughout the boroughs, the boundaries being changed at intervals to meet consumption requirements. As the pressure requirements necessary for satisfactory service increase, there is a constant diminution of the low service areas with a corresponding increase in the Intermediate service consumption. The scarcity of coal and its consequent high cost in recent years has tended to augment the proportion of Catskill water used in the Intermediate service. As a result of the conditions mentioned, there has been a material reduction in the use of the Croton supply, and in 1918 the consumption of this water had fallen to about 196,000,000 gallons daily, which is substantially 50 per cent of the normal Croton yield of 390,000,000 gallons and 58 per cent of the minimum safe yield of 336,000,000 gallons daily from this watershed.

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[1] Discussions of this paper are requested and should be sent to the Editor

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This reduction in the use of Croton water had been foreseen by the engineers of the department and various plans had been contemplated for the utilization of more water from this source. In the main, the projects embraced steam pumping within the city limits, the generation of electric power at favorable locations in the Croton watershed, its transmission and the pumping of water from Croton lake into the Catskill aqueduct by motor-driven pumps, and hydraulic operated pumping plants in the city. This last project involves some elements of novelty, and it is thought that a brief discussion of the scheme may prove of interest to members of the Association.

In brief the plan contemplates the utilization of the power now lost in the operation of throttling the discharge of Catskill water from the High to the Intermediate service by the passage of this water through hydraulic turbines, and the conversion of the lost head into power capable of operating centrifugal pumps which would take Croton water from Low service mains and deliver it to the Intermediate service. Factors of importance in the consideration of a project are as follows:

1. The difference in gradients between the High or Catskill and the Intermediate services. This would be the nominal head on the turbines.

2. The difference in gradients between the Intermediate and the Low or Croton services. This would be the nominal lift of the pumps.

3. The friction losses involved in conveying the water to and from a turbine-pump installation. These would operate to reduce the available head and increase the lift mentioned in 1 and 2.

4. The nominal consumption in an Intermediate service area tributary to a proposed plant.

5. The fluctuation in consumption in the tributary area. Factors 4 and 5 are of importance in the determination of the capacity of an installation and the capacity and type of regulating devices.

6. The availability of large capacity mains under Intermediate and Low pressures in close proximity to the Catskill shafts. Mains of this character are essential to avoid excessive friction losses under 3.

During 1919 the matter was investigated by the author and all available data regarding consumption in various districts, pressure records, service gradients as existing and as anticipated in the near future, probable gradients at the sites of possible installations and the probable effect of proposed changes and additions to the distribution systems were examined and studied in detail. From the standpoint of economy in construction, least disturbance of existing conditions, and the maximum utilization of low service Croton water, the following locations of turbine pump installations gave the most promise.

1. Shaft 3 in the Bronx. This Catskill shaft is in close proximity to the Jerome Park reservoir from which Croton water would be obtained for the pumps. The discharge from the plant would enter existing Intermediate service feeders.

2. Shaft 17, Manhattan. This shaft is at Bryant Park on Sixth Avenue at 41st Street. A new main for the pump supply would be needed to connect with the existing large capacity mains in Fifth Avenue. The discharge would enter existing feeders.

3. Shaft 18, Manhattan. This shaft is at Broadway and Fifth Avenue opposite Madison Square. At this point Low and Intermediate service mains of large capacity (36 and 48-inch) are available in Fifth Avenue, adjacent to the shaft chamber.

Conditions at these locations are shown in table 1. The theoretical horse power developed by passing 1,000,000 gallons daily through the turbines and that required to lift 1,000,000 gallon daily by the pumps under the conditions given in table 1 would be as given in lines 7 and 8. This theoretical power would be modified by the efficiency of the apparatus, and the horse power per million gallons daily developed by the turbines and that required by the pumps with the ratio of the pump power to the turbine power for efficiencies of 80 and 75 per cent are given in lines 9, 10 and 11.

TABLE 1

Hydraulic data of plants for pumping water from Croton mains into intermediate service mains by pumps operated by Catskill water from High-service mains, the discharge from the turbines going into the Intermediate service mains

	CATSKILL SHAFT		
	1	2	3
1. Elevation of service gradient, feet			
2. High service	290	282	280
3. Intermediate service	220	180	160
4. Low service	133	95	90
5. Head on turbine, feet	70	102	120
6. Lift of pump, feet	87	85	70
7. Theoretical horse-power per million gallons daily developed by turbine	12.29	17.91	21.07
8. Theoretical horse-power per million gallons daily required by pump	15.27	14.92	12.29
9. Net horse-power per million gallons daily developed by turbine, 80 per cent efficiency	9.83	14.33	16.85
10. Net horse-power per million gallons daily required by pump, 75 per cent efficiency	20.36	19.90	16.38
11. Ratio of pump power to turbine power	2.07	1.39	0.97
12. Nominal daily consumption, gallons	45,000,000	35,000,000	65,000,000
13. Maximum daily consumption, gallons	58,000,000	49,000,000	81,000,000
14. Minimum daily consumption, gallons	32,000,000	21,000,000	49,000,000
15. Percentage minimum is of nominal	70	60	75
Daily plant output equal to entire supply			
16. Turbine, gallons	30,300,000	20,400,000	32,000,000
17. Pumps, gallons*	14,700,000	14,600,000	33,000,000
Daily plant output equal to minimum rate			
18. Turbine, gallons	21,600,000	12,200,000	24,100,000
19. Pump, gallons†	10,400,000	8,800,000	24,900,000
Daily plant output with 10 per cent regulation			
20. Turbine, gallons	28,300,000	18,000,000	30,600,000
21. Pump, gallons‡	13,700,000	13,000,000	31,400,000
22. Output, gallons	42,000,000	31,000,000	62,000,000
23. Bypassed, gallons	3,000,000	4,000,000	3,000,000

* Total utilization of Croton water, 62,300,000 gallons daily.

† Total utilization of Croton water, 44,100,000 gallons daily.

‡ Total utilization of Croton water, 58,100,000 gallons daily.

Assuming that the entire intermediate supply would pass through the turbine-pumps, the relative quantities of water handled under nominal conditions by the turbines and pumps are indicated in lines 16 and 17. These figures, being based on nominal average daily consumption, indicate a use of Croton water through the pumps greater than could ever be realized in practice, inasmuch as a plant of the character under consideration would not have sufficient flexibility to follow the variation in consumption in a tributary district.

An examination of chart records from large Venturi meters gave valuable information regarding the fluctuation in consumption through the 24 hours of a day. It was of interest to note that the minimum rate, which usually occurred at 3 or 4 o'clock in the morning, showed much smaller variation than the maximum rate, which as a rule was found about 9 o'clock in the morning. The former is probably influenced by leakage, which is a constant factor. The latter is influenced by the season of the year and by the day of the week, reaching a maximum value in extremely hot or cold weather. In office and business districts the daily maximum usually was found on Monday and the minimum on Saturday afternoon and Sunday. In residential districts the maximum was usually noted on Saturday, Sunday or a holiday. The above tendency tends to stabilize the consumption of the city as a whole. The departure of the extreme rates indicated by the charts from a 24-hour average practically balanced; that is, the swing from mean to maximum equalled the swing from mean to minimum rates. The consumption range between recorded maxima and minima showed a tendency to decrease with an increase in the size of a district and the total consumption.

TABLE 2

SHAFT	DISTRICTS	APPROXIMATE DAILY FLOW	RANGE IN PERCENTAGE OF 24-HOUR AVERAGE	
			Maximum	Minimum
		gallons		
2	Catskill water supplied to city tunnel.	400,000,000	120	80
3	Largely residential....................	30,000,000 20,000,000	135 140	65 60
17	Hotel and business.....................	35,000,000	140	60
18	Office, business and water front.......	65,000,000	125	75

The magnitude of the range in some of the districts studied is given in table 2, the maxima and minima being values which occur but few times a year.

To illustrate the hourly fluctuation in consumption figure 1 is reproduced from the Venturi meter records. On this diagram the average daily flow for a typical week and that on the maximum and minimum day from Shaft 17 and Shaft 18 are given. In connection with figure 1 it should be mentioned that in accordance with the method of curtailing consumption in the down-town district tributary to Shaft 18 in force when the records were taken, the lines do not represent a flow under uniform pressure, it being the practice to drop the feeding pressure about 10 pounds during the night hours and on Sunday.

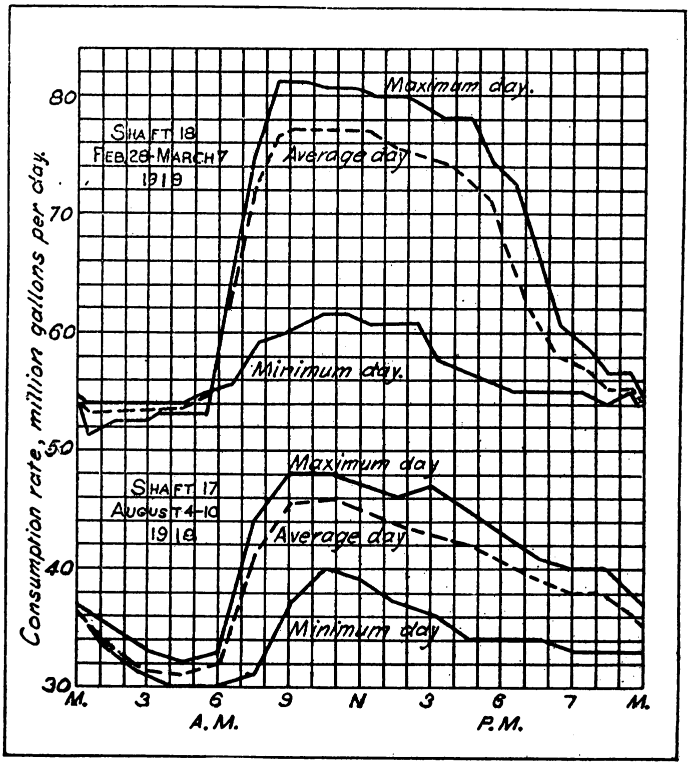

Fig. 1. Daily Flow to Intermediate Service from Shafts 17 and 18

The diagram indicates the conditions of fluctuating flow in districts which would be supplied by a turbine-pump installation. In the original design of the Catskill shaft outlets, the fluctuation in consumption was provided for by automatic regulation of the flow through the connections by means of pressure regulators set on bypasses around the main supply valves (see figure 2). In operation a main valve was set to deliver a quantity of water somewhat less than the minimum draft to the district and at the desired pressure. The regulator on the by-pass, when adjusted for the proper pressure change, automatically delivered water as required to follow

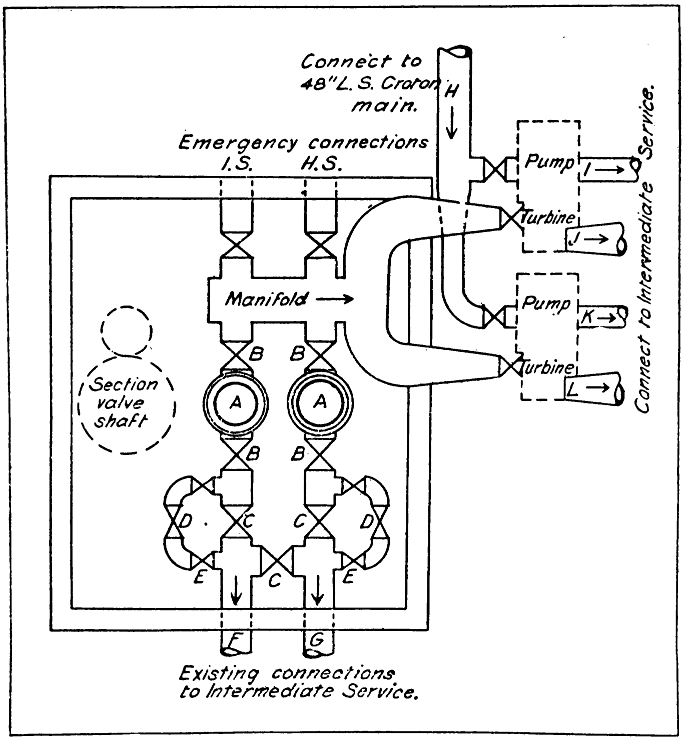
Connect to 48"L. S. Croton main.
H
Emergency connections
I.S. H.S.
Manifold
Section valve shaft
A
A
B B
B B
C C C
D D
E E
Pump
I
Turbine
J
Pump
K
Turbine
L
Connect to Intermediate Service.
F
G
Existing connections to Intermediate Service.

FIG. 2. PROPOSED TURBINE-PUMP INSTALLATION AT SHAFT 18

A, 48-inch Catskill shaft risers; *B*, 30-inch bronze valves, for emergency use only; *C*, 30-inch cast iron valves, for operating control; *D*, pressure regulators; *E*, 16-inch cast-iron valves; *F*, *G*, connections have Venturi meters; *H*, connection to have Venturi meter; *I*, *J*, *K*, *L*, discharge to be measured by meters in Intermediate service mains; valves on these connections not shown.

the consumption curve. The supply to the Intermediate service from shaft 17 is regulated satisfactorily in this manner and no regular attendance is provided in the shaft chamber. A pressure recording gage placed at this chamber indicated that the regulation was possibly somewhat sluggish; that is, the discharge did not exactly balance the consumption at all times with the result that the pressure at times built up slightly above normal and at other times fell below, the maximum variation noted on the chart records being about 7 pounds. At shaft 18, the delivery to the Intermediate service is in excess of the capacity of the automatic regulating devices and an attendant is stationed at this chamber to manipulate valves by hand to maintain a proper pressure and rate of discharge.

A turbine-pump installation designed to operate at practically constant speed and uniform delivery throughout the 24 hours of a day, of a capacity equal to the minimum rate of consumption with provision to supply all water required in excess of this minimum rate through automatic regulators, manual controlled valves or both would prove satisfactory in many respects. Plants operating on this basis at the shaft sites under consideration would utilize Croton water to the extent shown by lines 18 and 19 of table 1.

It is not thought advisable to depend upon automatic operation and regulation in installations of the capacity required at any of the shaft locations mentioned; attendance would be essential to safeguard against accident and to provide for emergencies. Furthermore with the probable extension of district boundaries and normal increase in consumption, the numerical value of the minimum rate would tend to increase and a plant designed for the minimum rate of today would not be able to utilize the proper portion of Croton water in the near future. With attendance at the stations, it would appear practicable to secure a certain variation in the discharge of turbine-pump units by changing the speed of the turbines within reasonable limits through the manipulation of the turbine wicket gates. Assuming that such regulation would result in a 10 per cent increase or decrease in output of the plant, operation would be as noted in lines 20, 21, 22 and 23.

The amounts of Croton water which would be pumped and made available under the assumptions heretofore made would be 62,300,000, 44,100,000 and 58,100,000 gallons daily. In practice the utilization of Croton water would probably fall between the last two sets of figures, but with not undue care on the part of the operatives it appears reasonable to assume that it would not be far from 50,000,000 gallons daily at the three points considered. Similar smaller plants are possible at other Catskill riser shafts, but data regarding them are omitted from the present paper.

Inquiries and a search through technical literature disclosed no instance where a plant was in existance in which the discharge from the turbine and that from the pump entered a common outlet. Instances where turbine-driven power or centrifugal pumps were in use were found, but in these cases the discharge from the turbines entered a reservoir or stream through the draft tube usual in hydraulic practice. A case was also noted where the discharge from one turbine was utilized to operate a second turbine, the two units being in tandem. Manufacturers of hydraulic turbines, however, appeared to note no great difficulty in operating a turbine in the manner desired.

It is apparent that to secure efficient operation of a unit, the various service gradients must be maintained at substantially the elevations assumed in the design. At the three sites considered in this paper, the gradients of the High and Low service would be very stable but the Intermediate service gradient would be subject to considerable fluctuation unless water in proper quantities was by-passed around a unit to hold up the pressure. The experience obtained with the present methods of supplying the Intermediate districts indicate, however, that it is entirely practicable to maintain a satisfactory gradient by bypassing at the proper times. Should the consumption in a tributary district fall at any time below the output of the turbine-pump units, due to shutting off large mains for repairs or other causes, this output could be reduced by throttling the pump discharge or by bypassing water through a gate or relief valve from the Intermediate to the Low service. Should the draft in a tributary district be suddenly augmented by a serious break in the mains at any point, with a consequent sudden drop in pressure, the discharge from the shaft chamber would have to be controlled by closing the inlet valves on the turbines and pumps or the main riser valves in the Catskill shafts.

The present Catskill shaft chambers are underground structures just below the street level, and turbine-pump units with controlling valves, etc., would be housed in similar chambers adjacent to or forming an extension of the existing chambers, To facilitate the work of inspection and repair and to avoid deep operating rooms, turbines and pumps of the horizontal type are proposed, the turbines to be of the scroll-case type equipped with hand-operated wicket gates. A governor to maintain constant speed is not deemed advisable. In the absence of a constant speed governor, a slight increase in pressure in the Intermediate system due to a falling off in consumption below the plant output would tend to reduce the head on the turbine and increase the lift of the pump; thus causing a slowing down in the operating speed with a resultant reduction in discharge. A decrease in pressure would operate in the opposite manner. Suction difficulties are obviated in the case of the pumps since water from the Low service supply would be delivered in the chambers under a head; for example, the operating floor at shaft 18 would be about elevation 30.

The preliminary studies indicated that the location at shaft 18 would be the most economical as regards unit capacity and would handle the greatest quantity of Croton water, consequently tentative plans were made for an installation at this point in the summer of 1919. At that time it was estimated that a suitable chamber containing two turbine-pump units of 65,000,000 gallons daily total capacity, with the necessary valves and connections with existing mains, would cost about $85,000, of which $12,000 was allowed for the turbine-pumps. The operating speed of the units would vary with the type selected and would be between 600 and 900 r.p.m. The floor space required for a single turbine-pump unit would be from about 100 to 70 square feet.

A possible layout is shown by figure 2. In this case the bypassing for regulation would be done by means of the existing valves and piping connected to the two southerly riser outlets. Based on the above estimate of cost, the cost per million gallons to pump Croton water with the hydraulic plant would be about one-quarter the cost of pumping at the existing steam stations.

On account of the presence of the Victory Arch on the site of the proposed station, it was impracticable to proceed with any construction at the time the studies were made and the favorable yield of the Esopus watershed in the summer and fall of 1919 lessened the anticipated need for greater utilization of the Croton supply. Should the yield of the former watershed fall much below the normal such utilization will become necessary and the proposed plant may become a reality.